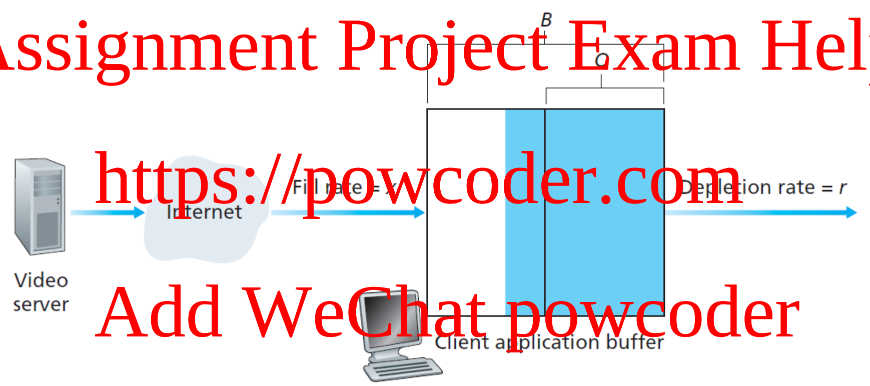
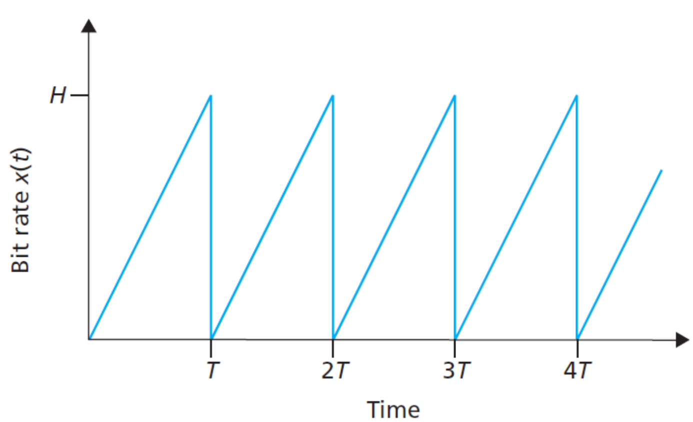
1. Recall the simple model for HTTP streaming shown as follows. B denotes the size of the client's application buffer, and Q denotes the number of bits that must be buffered before the client application begins playout. Suppose the buffer size is infinite but the server sends bits at variable rate $x(t)$. Specifically, suppose $x(t)$ has the following saw-tooth shape. The rate is initially zero at time $t = 0$ and linearly climbs to H at time $t = T$. It then repeats this pattern again and again, as shown in the figure below.

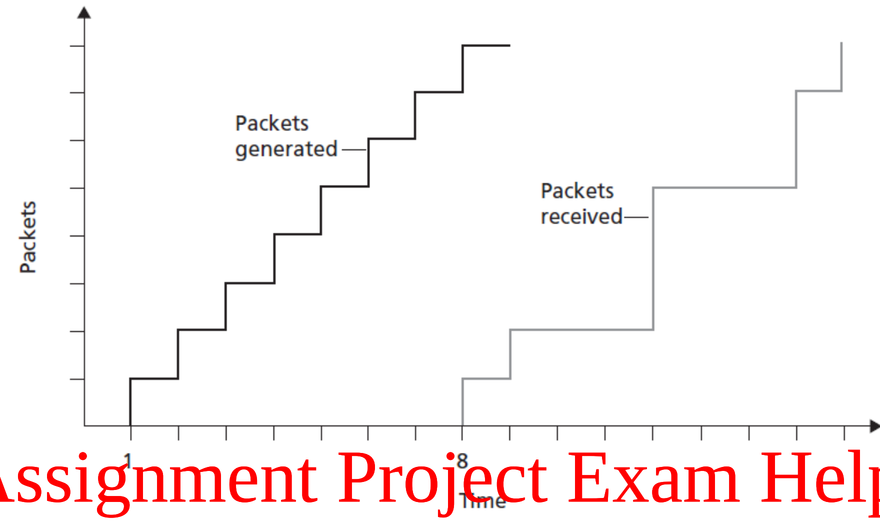
(1). What is the server's average send rate? H/2
(2). Now suppose $Q > 0$. $Q<HT/2$. Determine as a function of Q, H, and T the time at which playback first begins.
$\sqrt{2QT/H}$
(3). Suppose $H > 2r$ and $Q = HT/2$. Prove there will be no freezing after the initial playout delay.
Start to play at T.
In [T, T+t], t<T, the data volume at buffer is $Q - rt + \frac{Ht^2}{2T}$, which is always positive.
In [2T,2T+t], t<T, the data volume is $Q + (\frac{H}{2} - r)T - rt + \frac{Ht^2}{2T}$, which is always positive.
In [3T,3T+t], t<T, the data volume is $Q + 2(\frac{H}{2} - r)T - rt + \frac{Ht^2}{2T}$, which is always positive.
…
Similarly, in any [kT,kT+t], there is no freezing.





2. Consider the figure below. A sender begins sending packetized audio periodically at $t = 1$. The first packet arrives at the receiver at $t = 8$.

(1). What are the delays (from sender to receiver, ignoring any playout delays) of packets 2 through 8?
(2). If audio playout begins as soon as the first packet arrives at the receiver at $t = 8$, which of the first eight packets sent will *not* arrive in time for playout?
(3). If audio playout begins at $t = 9$, which of the first eight packets sent will not arrive in time for playout?
(4). What is the minimum playout delay at the receiver that results in all of the first eight packets arriving in time for their playout?



1) 7 7 9 8 7 9 8 8
2) Packets 3, 4, 6, 7, and 8 will not be received in time
3) Packets 3 and 6 will not be received in time
4) No packets will arrive after their playout time if playout time begins at t=10